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Archaeological use of Synthetic Aperture Sonar on deepwater wreck sites in Skagerrak

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ABSTRACT

Marine archaeological surveying in deep waters has so far been challenging, mainly due to operational and technological constraints. The standard tool has been Side Scan Sonar (SSS) towed behind a surface vessel. Synthetic Aperture Sonar (SAS) technology is not subject to the traditional range/resolution tradeoff, and produces results of considerably higher quality than traditional SSS. In 2015 and 2016 a comprehensive mapping of wrecks in Skagerrak, a large deepwater area off the south coast of Norway was undertaken, using an interferometric SAS system deployed on an autonomous underwater vehicle. By examining data from two passes of one of the many historical wrecks that were detected in the survey area, we demonstrate how SAS can be used to produce very high resolution imagery and bathymetry of wreck sites. Furthermore, post processing techniques are applied to exploit the high information content inherent in SAS data, enhancing aspects of the data for relevant archaeological analysis and interpretation. We show in this paper how SAS technology represents significant improvements in our abilities to conduct high quality and high resolution seabed mapping. The adoption of this technology will both benefit archaeological research and provide knowledge for better decision making in underwater cultural heritage management.

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1. Introduction and background

There are practical and physiological constraints limiting the use of human divers for seabed surveying beyond very shallow depths. To explore, investigate, map and monitor in deeper waters we must rely on remote sensing technologies to provide data. Due to the inherent optical properties of water, light has limited range, and acoustic sensing has been the technology of choice for most marine sciences for larger area seabed mapping (Singh et al., 2007). Marine archaeology was an early adaptor of such technology, and has used Side Scan Sonar (SSS), Multi Beam Echo Sounders (MBES) and Sub Bottom Penetrating Sonars to detect, map and monitor cultural heritage on the seabed for decades (Bates et al., 2011). As acoustic sensors have developed over the years, data quality has improved significantly. However, the range-resolution tradeoff has always been a matter of fact, and applicants of underwater acoustics for seabed mapping have always had to make compromises best suiting their particular needs (Quinn et al., 2005). With the advent of Synthetic Aperture Sonar (SAS) technology, this no longer is the case. The resolution of SAS imagery does not depend on wavelength (frequency), and SAS can therefore operate at long range (several hundreds of meters) and at the same time retain a consistently high resolution (centimeters) (Hansen, 2011). The sophisticated technology comprising the sensor, the strict requirements for precise platform navigation and the computer intensive and complex post processing needed to produce high quality SAS data has so far curbed widespread use of the technology in marine archaeology.

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The rapidly advancing developments within underwater robotics and computer technologies are likely to change this within the coming years, as the technology becomes more commercially available and easier to use (Hagen et al., 2008; Hansen, 2013). The few published examples of SAS used in marine archaeology have mainly showcased the potential (R. E. Hansen et al., 2009; Roman and Mather, 2010; Lawrence, 2011; Ødegård et al., 2013).

After WWII stockpiles of chemical weapons and munitions were a safety issue on the allied agenda. The disposal of huge amounts of highly dangerous materials was a problem, and the solution corresponding to the period was to dump it in the ocean. Convoys of discarded ships were filled with munitions, and in various manners sunk more or less within designated deepwater areas. Today this historical idiocy poses huge environmental and health safety problems many places around the globe, and the need for detailed information of locations and states is crucial for making good and safe management decisions (Long, 2009). In 2009, 2015 and 2016 the Norwegian Defense Research Establishment (FFI) and the Norwegian Coastal Administration have cooperated on detailed mapping of dumping fields just off the Norwegian coast in the Skagerrak Strait (C. M. Hansen et al., 2009; Sæbø et al., 2015). In addition to finding many of the wrecks from the post WWII dumping, the survey also discovered a number of other wrecks that appeared to be much older (Fig. 1).

The Skagerrak strait links the Baltic Sea to the North Sea, and thus the rest of the world. It lies between Norway, Sweden and Denmark, and is today one of the most heavily trafficked sea routes in the world. We can assume that it has seen human seafaring since the Mesolithic era (Gaffney et al., 2007), and we know that it has been a very important commercial and political seaway since at least the Viking age. The Øresund Sound Toll was a tax the Danish king levied on all ships passing the narrow strait leading into the Baltic just south of Skagerrak in the period 1497–1857 (Gøbel, 2010). The records are accessible for online search and show that a total of 1,8 million passages were registered for the whole period (east- and west-bound). For the period 1634–1700 an average of 3146 passages each year, for the following periods respectively; 1701–1750: 3365 passages; 1751–1800: 8013 passages; 1801–1857: 12563 passages (http://dietrich.soundtoll.nl/public/stats.php?stat=py). The weather in this area can be rough (Lamb and Frydendahl, 1991), and a considerable number of vessels have been lost in the open seas of Skagerrak. An estimation by Willard Bascom (1976) that about 10% of all ships that ever sailed sunk in open seas, has been corroborated for the region by analysis of databases from modern times by Gundersen et al. (2008). The latter also conservatively estimates that at least 10.000 ships have sunk in the Norwegian sector of the North Sea alone. We do not have information of how many ships have gone down in the adjacent Skagerrak area, but given the high sailing frequency and that losses at open seas were common, we can safely assume that the total number must be very high – at least several hundreds. The underwater cultural heritage deposited on the Skagerrak seabed represents invaluable sources for knowledge of our history for the last few thousand years. Most of Skagerrak is considered a shallow sea, with depths around 90 m. The exception is the Norwegian trench that extends down to around 700 m, and this includes the surveyed area. The seabed geology in the deepest parts is characterized by meters thick fine grained sediments deposited over the last 13,000 years (Gyllencreutz et al., 2006), potentially very benign environments for preservation of shipwrecks. As for deeper waters all over the world, depth has been a methodological barrier for high resolution seabed surveying and mapping.

This paper briefly describes the principles behind SAS and how it differs from traditional SSS in terms of data acquisition, processing and products. We argue that SAS technology deployed on Autonomous Underwater Vehicles (AUVs) represents great methodological progress in our abilities to detect and record underwater cultural heritage. The paper aims to substantiate this claim by presenting and discussing data from deepwater wreck sites in Skagerrak, and by demonstrating post processing techniques for enhanced archaeological interpretations.

2. Method and materials

2.1. Sensor and platform

Traditional (real aperture) sidescan sonar systems produce imagery where mainly wavelength and array length determine along-track resolution, and pulse bandwidth determine across-track resolution (Blondel, 2009). It follows that a high frequency system will give high resolution both across and along track for short ranges, but with increased range the along-track resolution is impaired by wider beam and longer pulse repetition intervals. Acoustic absorption in seawater depends on frequency, such that higher frequency signals have shorter range than lower frequency signals. Therefore, frequency can be lowered to gain longer ranges, but at the cost of lower resolution (Lurton, 2010). In contrast, along-track resolution for a SAS system is determined by the false length of the array (i.e. synthetic aperture) – which is a function of range (Massonnet and Souyris, 2008). It is thus independent of frequency - which is a notable difference from real aperture sidescan sonar. By creating a ‘false’ array, even longer than the platform carrying it (Fig. 2), the signal can be refined by using multiple echoes to focus on very small areas on the seabed, enabling much smaller pixels in the produced seabed imagery (Fig. 3). By arranging an array consisting of multiple receivers, the SAS system uses beamforming to focus the received signal in particular directions. Furthermore, by processing phase coded transmit signals from consecutive pings the SAS system can benefit from high energy signals (i.e. longer range), while retaining large bandwidth. Delaying the signal from each receiver for every ensonified pixel, and then summing the signals in each pixel, will result in SAS imagery that have rich data basis providing a high signal to noise ratio (SNR). For a thorough overview of SAS principles see Hansen (2011).

SAS image quality depends on both navigational and environmental factors. To ensure a consistent along-track resolution, the length of the synthetic array increases with range. Hence the quality of longer range SAS depends heavily on accurate measurements of platform velocity and attitudes, in addition to sound velocity. The performance of the platform is of vital importance for the quality of the SAS data. Not surprisingly AUVs with high end aided inertial navigation systems are the commonly preferred platforms for this sensor, although there are examples of towed platforms as well. Main issues regarding AUV as instrument carrier for SAS for this kind of survey are: vehicle stability, attitude compared to direction of survey line (i.e. crab) and trim (Sæbø et al., 2015). Also navigation with a set altitude above seabed could cause the vehicle to do frequent pitching if the bathymetry is uneven (Hansen et al., 2011). The 2015 and 2016 Skagerrak surveys were conducted with a HiSAS 1030 interferometric sensor deployed on HUGIN HUS, a Kongsberg Maritime HUGIN 1000 AUV operated from the surface vessel H.U. Sverdrup II. A range of other sensors were also deployed on the AUV. A short summary of HiSAS 1030 properties is presented in Table 1, for an overview of HUGIN 1000 see Hagen et al. (2003).

2.2. Post processing

After download the initial processing step is to use a wavenumber algorithm (frequency domain) to transform raw data (low

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